Renewable and Sustainable Energy Reviews 33 (2014) 719–728

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Sustainable management of waste-to-energy facilities ☆

Federica Cucchiella *, Idiano D'Adamo, Massimo Gastaldi

Department of Industrial and Information Engineering and Economics Faculty of Engineering, University of L'Aquila, Via Giovanni Gronchi 18, Zona Industriale Pile, 67100 L'Aquila, Italy

ARTICLE INFO

Article history:
Received 16 July 2013
Received in revised form
31 December 2013
Accepted 8 February 2014
Available online 15 March 2014

Keywords:
Waste management
Energy recovery
Quantitative analysis
Sustainability

ABSTRACT

In 1995, Porter and van der Linde defined pollution as a manifestation of economic waste. Currently, incorrect information and conflicting theories among scientists hinder the diffusion of sustainable practices in waste management [1]. New industrial market research reports highlight that the value of the global waste incineration market has increased in recent years (+$1.3 billion dollars from 2008 to 2012), and this sector will continue to grow (+$6.8 billion dollars from 2012 to 2022) [2].

The paper focuses on the Italian situation on which urgent actions are required because more than 50% of waste is landfilled [3]. The correct environmental management increases the financial performance because waste investments offer both environmental and economic benefits. The problem to solve is related to both waste management and high levels of recycling, where an unsorted fraction of waste will remain. Based on a thorough review of the topic, a national waste management plan (NWMP) for energy recovery is herein proposed for evaluating all the aspects of sustainability of waste-to-energy (WTE) plants: the reduction of greenhouse gases (GHGs) with respect to landfill, the estimation of financial net present value (FNPV) and the economic net present value (ENPV) and, finally, the estimation of new employment opportunity.

Contents

☆ Special thank is due to "L.P.S. to infinite".

* Corresponding author.
E-mail addresses: federica.cucchiella@univaq.it (F. Cucchiella), idiano.dadamo@univaq.it (I. D'Adamo), massimo.gastaldi@univaq.it (M. Gastaldi).

http://dx.doi.org/10.1016/j.rser.2014.02.015
1364-0321

1. Introduction

The global population is likely to grow, and the rapidly increasing standards of living in some developing countries, along with the escalating accumulation of greenhouse gases in the atmosphere, make the goal of sustainability increasingly urgent [4,5]. This topic continues to attract a significant amount of attention within the academic, managerial and policy-making communities [6,7]. Sustainable development requires viable answers following economic, social and environmental criteria [8]. Interdisciplinary research (e.g., between the above criteria) is increasingly recognised as an essential cornerstone for linking together specialised knowledge [9]. A literature review of quantitative studies offers interesting implications for managers, as a real commitment to green management may result in positive influence on financial performance [10]. With investments in renewable energy, investors gain access to reliable and healthy long-term returns at low risk. This is a sector characterised by relevant growth, and with the definition of renewable energy goals and portfolio standards, it is possible to meet short- and long-term objectives for renewable energy [11].

The generation of electricity, heat or biofuels from renewable energy sources has become a high priority in energy policy strategies at the national level as well as on a global scale [12]. An analysis of the protection policies of the United States indicates that strong environmental programs result in lower levels of pollution and better public health [13]. Environmental corporate social responsibility generates new and competitive resources for firms. Waste management can lead to achieving significant financial benefits, and, in the case of waste management violations, the firms are subject to substantial fines or civil penalties [14].

This paper aims to study the sustainability of WTE plants. Thus, a multisectorial analysis is required for evaluating all aspects necessary to reduce pollution, to create new jobs and to provide financial and economic benefits. The paper is organised as follows. Initially, the role of WTE plants in waste management is described (Section 2), and some statistics are presented describing waste management and resource recovery in Italy (Section 3). The data indicate growing waste production. Moreover, the data also indicate separate collection rates of municipal waste management (MSW) which are increasing in all Italian regions for all waste fractions. However, the share of separate collection is increasing more slowly than in other European countries. Previous papers underline that it is proper to proceed with regional plans finalised at the realisation of incinerators with energy recovery. In this manner, an appropriate NWMP allows a considerable reduction of 34% in landfilling [14–16]. A multi-sectorial sensitivity analysis for an in-depth evaluation of NWMP is presented, and the input data required to evaluate the NWMP of incinerators investments are described (Section 4). Specifically, facilities realisation is evaluated according to several points of view:

- Environmental: computing emissions of kg of equivalent CO_2 avoided incinerating a metric ton of waste instead of placing it in a landfill, and this was also the case of modern landfill with biogas capture. To take into account several aspects (incineration operation, biogas capture option), several scenarios are analysed.
- Financial: evaluating market conditions and how financial revenues (FNPV) depend on critical inputs (selling price of electricity, lower heating value, heat selling price, investment cost and interest rate).
- Economical: evaluating ENPV that, differently by Public Benefits (WPB), accounts both for externalities and market failures.
- Social: quantifying the new employment opportunity due to the facility realisation.

The sustainability of the national incinerator plan is also evaluated by a sensitivity analysis (Section 5), and some final remarks are also presented with the aim of promoting the sustainability of a mixed waste strategy in real case applications (Section 6).

2. Literature review

Sustainable waste management (SWM) has a central role in sustainable development. It varies regionally and also depends on waste composition. According to an analysis provided by a research company in North America, landfills are by far the preferred methods of disposal for MSW [15,16]. In China, the government is depending on all forms of SWM, including WTE, to minimise and reduce anticipated future waste management burdens [17].

Over 80% of MSW in China is still being disposed of in anaerobic landfills [18]. The appropriate MSW management in China is crucial to solving problems caused by the large generation and accumulation of wastes [19]. It is estimated that MSW incineration will account for approximately 35% of waste elimination by the end of 2015 [20]. Recycling is necessary, but China is facing several obstacles: the improvement of public awareness, the limitations of traditional garbage classification, the lack of laws and regulations, and the garbage of recycling facilities is not complete [21].

The Southern European Union (EU) countries need to develop further measures to implement more integrated MSW management and reach EU directives, whereas the Central EU countries need models and tools to rationalise their technological choices and management strategies [17].

As shown in Table 1, Germany, The Netherlands, Belgium, Austria, Sweden and Denmark represent the more advanced countries from an environmental point of view. The benefits derived from a proper MSW management include greenhouse gases emission prevention, pollutants reduction, energy saves, resources conservation, new jobs creation, development of green technologies and economic opportunities [3].

Public relations issues remain to be solved as in many territories it is believed that incinerators are more polluting then landfill. A holistic approach has been introduced to evaluate social acceptance of renewable energy [22]. In contrast to previous models, this model specifically analyses market acceptance in addition to public and political elements. Reputable firms are more likely to invest in the clean energy sector and utilise risk reduction strategies more extensively [23]. An interesting paper asks: “Profit or sustainable advantage, what should be the dependent variable for strategy?” [24].

The value of the global waste incineration market was equal to \$9.2 billion dollars in 2012, up from \$7.9 billion dollars in 2008. By

Table 1
Landfill usage in Europe (2011).

% MSW in landfill	Countries
Less 5%	Germany, the Netherlands, Austria, Belgium, Sweden, Denmark
Between 5% and 30%	Luxembourg
Between 30% and 40%	France, European average
Between 40% and 50%	Finland, United Kingdom
Between 50% and 60%	Italy, Ireland, Spain, Slovenia
Between 60% and 75%	Portugal, Czech Republic, Hungary, Poland
Between 75% and 90%	Estonia, Cyprus, Slovakia, Greece, Malta
Between 90% and 100%	Latvia, Lithuania, Romania, Bulgaria

Table 2
Unit costs and units' efficiency from different energy sources.

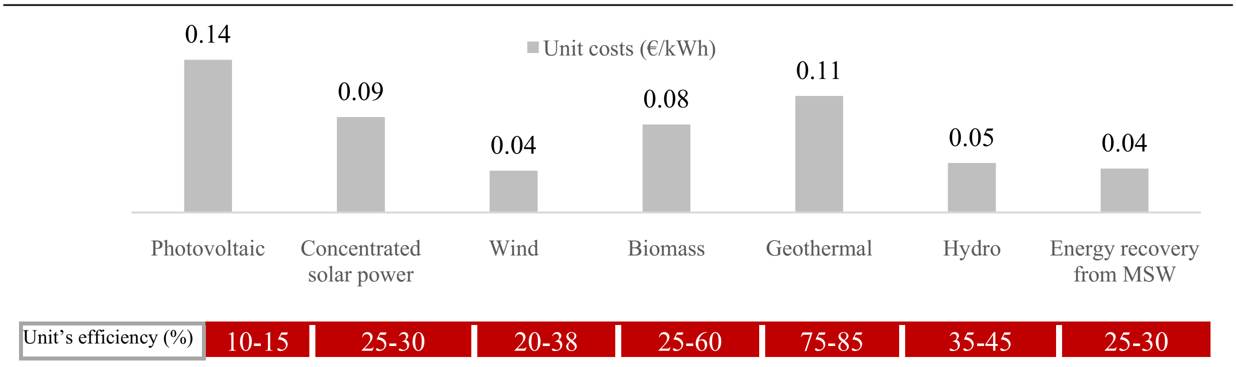

Table 3
Life cycle CO_2 emission per kWh of electricity.

Source	U.S. Environmental Protection Agency, 2005 [58]	IEA Bioenergy, 2003 [59]
MSW	457	367
Coal	1012	987
Oil	752	–
Natural Gas	511	446

2022, the growth will more than double with a new value equal to \$16.8 billion dollars [2]. In Europe, the WTE market reached revenues of approximately 4.22 billion dollars in 2012, and it is estimated to grow through 2016 [25].

SWM based on the reduction of landfill disposal is an important aspect of public health and environmental protection [7,26]. In comparison with other renewable energy production sources, the potential energy that can be produced from MSW presents significant benefits, both economic (unit costs) and technical (unit efficiency), as shown in Table 2 [27].

The generation of heat or electricity with the combustion of MSW could reduce net greenhouse gas emissions compared with the combustion of methane required by landfills. The feasibility assessment of investments in waste incineration facilities with energy recovery depends on methane emissions that alternatively are released from landfill, CO_2 emissions derived from energy production from fossil fuel and not by wastes (Table 3) and CO_2 emissions derived from the production of metals that can be avoided via recovery and recycling.

A reduction of MSW in terms of the garbage amount disposed by landfills is strongly desired. At the same time, according to the European Environment Agency, simultaneously increasing recycling and energy recovery helps to achieve the emission targets. This represents savings (or avoided greenhouse gas emissions) that can offset direct emissions [28].

A WTE facility is only one component of waste management and has to be harmonically integrated with source reduction, recycling and landfill. In these facility materials, such as paper, metal, plastic and glass are recycled and recovered, whereas other materials, which cannot be reclaimed, are typically incinerated.

The WTE process is an effective method for responding to climate change arising from the global warming effect. The relevance of WTE will continuously increase by converting non-recyclable waste materials into electricity and heat. In this manner, it will be possible to generate renewable energy and reduce carbon emissions by offsetting the need for energy from fossil sources and reducing methane generation from landfills [29,30]. Waste combustion is influenced by several factors: the MSW composition, the air supply rate and the heat transfer between the solid and gaseous phases [31,32].

3. Current status in Italy

According to ISPRA, the total waste production in 2010 in Italy was approximately 32,500 kt (+1.1% higher than 2009), and the share of separate waste collection was 35.3%, a target that was to be achieved in 2006 [33]. Wastes diverted to landfill are approximately 50% of total production, and this share is considerably larger than other European virtuous countries where the use of landfills is less than 3%.

Per inhabitant waste production is approximately 529 kg/cap at the national level, and the highest values are in Emilia Romagna and Toscana (677 and 670 kg/cap, respectively), whereas the minimum value is in Basilicata (376 kg/cap) as shown in Table 4. The table also shows the wastes landfilled per capita with strong differences among regions. The lowest levels are in Lombardia (49 kg/cap), Friuli Venezia Giulia (139 kg/cap) and Veneto (142 kg/cap). The highest levels are in Liguria (563 kg/cap), Sicilia (516 kg/cap), Lazio (498 kg/cap) and Puglia (479 kg/cap).

This paper belongs to a wider area of research where a plan for the optimal management of unsorted waste for each region has been defined, based on multi-level analysis. The NWMP, developed with a particular focus on energy recovery, allows a 34% diversion of waste from landfills [5,34] with the used strategy based on recycling and energy recovery. To obtain generalisable results, not linked to the input data, several scenarios based on different levels of landfill use have been hypothesised: share of waste energy recovery of 75% ($WtoE^{75\%}$), energy recovery of 75% but with a maximum level on dimensional incinerator facilities of 500 kt ($WtoE^{\delta(75\%)}$), energy recovery of 50% ($WtoE^{50\%}$) and energy recovery of 25% ($WtoE^{25\%}$). In this context, due to the phenomena of not in my back yard (NIMBY) or not in my term of office (NIMTO), possible social opposition movements to infrastructure development (especially large plants) can arise. Thus, the quantification of the costs of not implementing such projects is necessary. For example, a 1-year delay realisation of $WtoE^{75\%}$ NWMP (with a lifetime of 30 years) is responsible for a revenue loss of 36 M€ [34].

Alternatively, large facilities can be replaced with more than one smaller incinerator. In this case, the environmental result is the same, but the financial results are strongly different. From a social perspective, the construction of large facilities may be appropriate only in regions with high levels of waste production. In Italy, this is the case of Brescia (a city located in the northern

Table 4
Total municipal waste generated and landfilled by Italian regions (kg per capita).

Region	Total	Lnd	Region	Total	Lnd	Region	Total	Lnd	Region	Total	Lnd
Emilia R.	677	255	Umbria	597	340	Piemonte	505	229	Veneto	488	142
Toscana	670	339	Marche	536	335	Lombardia	500	49	Campania	478	180
V. d'Aosta	624	396	Puglia	526	479	Friuli V.G.	494	139	Calabria	468	256
Liguria	613	563	Sicilia	517	516	Sardegna	493	286	Molise	413	393
Lazio	599	498	Abruzzo	507	401	Trentino A.A	491	157	Basilicata	376	274

Table 5
Emissions from waste to energy (mg/Nm^3) – the Brescia case.

Emission	NO_X	SO_X	CO	Particles	Heavy metals	Dioxins
Target	200	100	50	10	0.5	<0.01
Plant emissions	80	30	20	0.2	0.015	0.1
Reduction	**−60%**	**−70%**	**−60%**	**−98%**	**−97%**	**−90%**

part of the country), where a waste incinerator has been constructed for non-recyclable wastes. In 2006, the plant was selected from a list of some of the best WTE facilities receiving the WTERT Industry Award [35]. In 2011, it burned 796 kt of refuse and biomass fuel, simultaneously generating 600 million kWh and 747 million kWh of thermal energy. The combination of the remote heating system and the waste incinerator power plant has allowed the Brescia territory to reduce CO_2 emissions by approximately 400,000 tCO_2eq. Any residual waste not incinerated during the combustion process (equivalent to approximately 10% of the entire volume of refuse treated by the plant) is transferred into authorised landfills, whereas powders collected from the incinerator's filters are sent to storage silos. In this manner, Brescia achieved the emissions targets required by Italian laws (Table 5).

The necessity of implementing a national plan for waste incineration has also been confirmed by research on European countries in the period 2009–2016, [25]. Among European countries, Italy is expected to become one of the most attractive market for energy waste production (currently, there are 55 WTE incinerators). Therefore, in the short-term, Italy will be an attractive market for the modernisation of old technologies to provide greater energy efficiency.

4. Input data for NWMP implications

The NWMP has been defined on the basis of economic, financial, environmental and social aspects. It requires selecting and evaluating input data necessary to individuate different scenarios and a sensitivity analysis to strengthen the basis of the proposed sustainability policy and development.

4.1. Methodology

The methodology used is based on several steps. In this section, the approach applied to accomplish the final aim of the paper is described. The analysis was initially performed for each Italian region, and then the results were combined to define the NWMP. The steps are as follows:

1. Analysis of the current Italian situation and of the waste management mix: compared with other European Countries, in Italy there is excessive landfill use.
2. Literature review: based on European Commission Waste Hierarchy and the European Countries experiences, it is possible to identify energy recovery as the most suitable management for unsorted waste. This initiative is complementary to, and not a replacement of, recycling.
3. Plant capacity study: as to not limit the results to a specific size facility, several sizes of facilities are analysed (from 50 to 750 kt, at multiples of 50 kt).
4. Development of a national plan: based on previous results, it verifies whether it is desirable to develop a NWMP characterised by the implementation of WTE plants.
5. Definition of future scenarios related to the waste generation and its composition.
6. Identification of possible energy recovery management methods that can be adopted.
7. Adoption of a multi-criteria analysis to define, for each hypothesised policy of waste to energy, the optimal size of the plants that allows achieving the economic and sustainable aims.
8. Optimal plant sizing: it is an estimate of the waste valorisation (WV). It is also necessary to estimate the reduction of pollutant emissions (GHG) depending on the type of landfill that is replaced by WTE.
9. Estimation of FNPV for each facility size.
10. Sensitivity analysis to identify the FNPV critical variables and FNPV estimation under dynamic scenarios.
11. Estimation of ENPV, both for base scenarios and in dynamic cases characterised by different values of social cost of carbon (related to the type of landfill that is replaced by the WTE).
12. Estimation of new jobs generated by the implementation of each plant.
13. Definition and analysis of the NWMP and estimation of related GHG.
14. Estimation of FNPV related to NWMP under basic and dynamic scenarios.
15. Estimation of ENPV related to NWMP under basic and dynamic scenarios.
16. Estimation of new jobs generated by the implementation of the NWMP.
17. Sustainability analysis of the NWMP.

4.2. Input of environmental analysis

Environmental analysis is based on the quantification of reduction in greenhouse gas emissions, both those from landfills and from incinerators with energy recovery. An additional analysis is performed in the present work. A life cycle assessment (LCA) is used to conduct the landfill GHG study, and emissions generated directly and indirectly are taken into account, as are all revenues and costs. An upstream-operating-downstream model is adopted [36,37].

The developing countries, moving from open dumpsites to sanitary landfill with no provision for landfill gas capture, may have reduced GHG emission. The new generation of waste to energy methods achieves a significantly better environmental impact than those produced using older technology [29,38]. GHG landfill emissions vary in a wide range. In open dumpsites and landfill with no provision for landfill gas capture, the GHG amounts to

Table 6
Net GHG emissions from landfilling and incineration.

	$G\Delta LF^{trd}$	$G\Delta LF^{avg}$	$G\Delta LF^{cpt}$
Emissions reduction ($kgCO_2eq$/twaste)	650	500	360

1.2 tCO_2eq/twaste. In the case of effective gas collection and flaring, the emission factor improves to approximately 0.19 tCO_2eq/twaste. Emissions can be reduced (to 0.09 tCO_2eq/twaste) if the biogas is utilised for electricity production. The quantity of gas emissions, generally highest in developing countries, depends on waste composition. For example, reference values in Europe are 1 tCO_2eq/twaste in open dumpsites landfill, 0.3 tCO_2eq/twaste if the biogas is utilised for electricity production of waste and 0.07 tCO_2eq/twaste if there is a low organic carbon [39].

The European direct emissions from incineration with energy recovery are 347–371 $kgCO_2eq$/twaste and 735–803 $kgCO_2eq$/twaste for co-combustion. In addition, these estimates are based on the upstream-operating-downstream model [37]. Currently, there are factors that make WTE plants unsuitable or inadvisable in many developing countries. Notable among them are the high capital and operating costs involved and the comparatively low cost of sanitary landfilling. Moreover, incineration results in high waste moisture and low energy content [40].

Waste incineration plants have allowed Italy to achieve the maximum emissions target proposed by law: 50 mg/Nm^3 of NO_X (200 mg/Nm^3), 25 mg/Nm^3 of SO_2 (50 mg/Nm^3) and 10 mg/Nm^3 of CO (50 mg/Nm^3). Comparing incinerator facilities with energy recovery and landfill dispatching (provided of 50% landfill gas capture), the incinerator allows a GHG reduction of 360 $kgCO_2eq$/twaste ($G\Delta LF^{cpt}$) [22]. In the case of traditional landfill with no provision for landfill gas capture (with a correlated loss of biogas), the difference with respect to incinerators increases to 650 $kgCO_2eq$/twaste ($G\Delta LF^{trd}$). Given that the GHG reductions vary according to landfill characteristics, the future analysis is repeated using the two limits $G\Delta LF^{cpt}$ and $G\Delta LF^{trd}$ (estimated by ENEA) and also the average value $G\Delta LF^{avg}$ (Table 6).

Moreover, an additional analysis is required also inside each country as some problems are related to the status quo and characteristics of the waste produced [39,41]. For example, in Denmark, there are two incinerators with different characteristics. One plant allows a saving of approximately 480 $kgCO_2$, and the second saves 430 kg CO_2, per ton of waste. The results indicate that it is not sufficient to focus only on plant efficiencies when evaluating the performance of MSW incinerators.

4.3. Input of financial analysis

Unlike past beliefs, new knowledge creation and technologies make it possible to reconcile economic growth with environmental preservation. The green economy presents an alternative vision for growth and development: economic growth and improvements in people's lives are generated in ways consistent with sustainable development. This concept has piqued the interest of policy makers and businesses, presenting new opportunities for economic revenues [42,43].

For the financial index estimation, the total cost of investment in facilities is a key economic variable. It is calculated based on the total investment cost, and so it measures the performance of the investment independently of the sources or methods of financing, and does not assess the impact of the tax [44]. The incinerator facilities analysed in this paper are designed to produce 50% electrical energy and 50% thermal energy. It is a highly efficient system that captures heat lost during the production of electricity and converts it into useful thermal energy. Typically, these systems are 60–80% efficient, a value significantly higher than traditional power plants (approximately 30%). To model the FNPV analysis, the following basic assumptions are considered ($Input^{INT}$): lower heating value of 10.4 MJ/kg, selling price of electricity of 47.29 €/t, heat selling price of 27.02 €/t, investment cost can range from 376 to 765 €/t and interest rate of 5%. Starting with these input values, the sensitivity analysis is based on the following input pessimistic and optimistic ($Input^{PSM}$ and $Input^{OPT}$) variations:

- Interest rate can change in the new optimistic values of −2% and −1%, and the two new pessimistic values of +1% and +2% [44,45].
- Selling price of electricity and heat selling price can assume two higher optimistic values equal to +20% and +10%, with respect to the base value and two lower pessimistic values equal to −20% and −10%, respectively [44,45].
- Investment cost can assume two higher optimistic values equal to −20% and −10%, respectively, with respect to the base value and two lower pessimistic values equal to +20% and +10% [44,45].
- Lower heating value can assume two optimistic values and a pessimistic value 12.6 MJ/kg, 10.9 MJ/kg and 9.2 MJ/kg [45,46].

Sensitivity analyses are repeated under these input variations, and, among all the results, for each plant size, the minimum and maximum value are selected (Table 7). The incinerator size has a relevant role in the FNPV results. According to the base case (related to the hypotheses originally defined for NWMP), for plant with a capacity lower than 350 kt, the achieved FNPV is negative. However, the sensitivity analysis indicates that, in the optimistic situation ($Input^{OPT}$), small variations in input variables result in the FNPV being positive with plants of 200 kt, whereas, for the pessimistic situation ($Input^{PSM}$), a positive FNPV is achieved only with a 750 kt plant [5,47].

Table 7 shows that for the same dimensional size WTE, analysing the table along the columns, the minimum FNPV is achieved in the following three cases:

- for facilities with a dimension size from 50 to 550 kt when there is an investment cost increase equal to 20%,
- for facilities with a dimension size from 600 to 700 kt when there is a selling price of electricity decrease equal to 20%, and
- for a facility of 750 kt when the interest rate is equal to 7%.

The maximum FNPV is, instead, related to the following two cases:

- for facilities with a dimension size from 50 to 200 kt with a 20% investment cost decrease and
- for facilities with a dimension size from 250 to 750 kt with an interest rate of 3%.

This analysis reveals a great variability in the obtained results, which highlights the relevant influence of input parameters on the system's financial performance.

4.4. Input of economic analysis

Market failures can lead to waste over-production. Environmental externalities are the primary market failure when economic decisions to produce and consume do not correctly account the environmental consequences of waste generated. Waste economic efficiency is attained when the amount of waste generated is optimal, i.e., the costs of reducing one unit waste are equal to the economic and environmental benefits of having one less unit of

Table 7
Financial revenue (M€) for facilities from 50 to 750 kt under Input^{INT}, Input^{PSM}, and InputOPT.

	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750
Input^{INT}	−17	−18	−18	−15	−11	−6	0.5	8	11	23	31	37	50	58	69
Interest rate															
3%	−13	−9	−3	7	17	29	42	57	66	86	101	114	133	150	168
4%	−15	−14	−12	−5	1	10	19	29	36	51	62	72	86	99	113
6%	−18	−22	−24	−23	−22	−18	−15	−10	−9	1	6	10	19	25	33
7%	−19	−24	−28	−29	−30	−29	−27	−24	−25	−18	−14	−13	−6	−1	4
Selling price of electricity															
20%	−13	−10	−6	2	10	20	30	42	49	66	78	89	105	118	133
10%	−15	−14	−12	−6	−1	7	15	25	30	45	55	63	77	88	101
−10%	−19	−23	−25	−24	−22	−19	−15	−10	−8	2	8	12	21	28	37
−20%	−21	−27	−31	−32	−33	−32	−30	−27	−28	−20	−16	−14	−7	−2	5
Heat selling price															
20%	−14	−13	−11	−5	1	9	18	28	33	48	58	67	81	93	106
10%	−16	−16	−15	−10	−5	2	9	18	22	36	45	52	65	76	87
−10%	−18	−21	−22	−20	−18	−13	−8	−2	−0.3	11	18	23	33	41	50
−20%	−19	−23	−26	−25	−24	−21	−17	−12	−12	−2	4	8	17	24	31
Investment cost															
−20%	−9	−5	−0.1	8	15	25	35	45	53	68	79	89	103	115	127
−10%	−13	−12	−9	−4	2	9	18	27	32	45	55	63	76	87	98
10%	−21	−25	−28	−26	−25	−21	−17	−11	−10	1	7	12	22	30	40
20%	−25	−32	−37	−38	−38	−36	−34	−30	−31	−21	−17	−14	−5	1	11
Lower heating value															
12.6 MJ/kg	−12	−14	−12	−3	−1	7	9	22	31	41	59	66	73	79	85
10.9 MJ/kg	−16	−17	−17	−15	−11	−3	5	14	16	26	39	46	58	65	80
9.2 MJ/kg	−20	−22	−22	−16	−13	−13	−10	−7	−2	15	16	17	28	42	42
							Maximun FNPV					Minimum FNPV			

Table 8
ENPV (M€) under different GHG emissions and for 50–750 kt plant sizes.

Size	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750
Input^{INT}	7	24	42	62	81	103	124	147	166	192	215	236	261	285	309
$G\Delta LF^{trd}$	6	22	38	57	76	96	117	138	157	181	203	224	248	270	293
$G\Delta LF^{avg}$	8	25	43	64	84	106	129	151	172	198	221	243	269	293	318
$G\Delta LF^{cpt}$	10	29	49	71	93	117	141	165	188	215	240	265	292	318	344

waste [48]. All costs and benefits associated with reducing wastes must be evaluated. The index used for the economic analysis is ENPV, which, differently from FNPV, is also positive for the 50 kt plant size. Before proceeding with ENPV estimations, the next subsection focuses on an externality (the social cost of carbon SCC), which is frequently not considered by market agents.

4.4.1. *Social cost of carbon (SCC)*

The critical variables of ENPV are the same individualised variables for FNPV with the addition of externalities [45]. SCC is the estimated price of the economic damages caused by each additional ton of CO_2 released into the atmosphere, and this value should, in theory, be set at the marginal damage cost of a unit of emissions. In other words, it represents the present value of the economic cost caused by one extra unit of greenhouse gas while it is in the atmosphere. According to literature, several solutions have been developed. According to the European Renewable Energy Council, the price should be 20 €/tCO_2eq, and the same value is estimated after an additional review: 211 estimates of SCC were gathered from 47 studies [49]. According to the obtained results, "the median of the Fisher–Tippett kernel density for peer-reviewed estimates with a 3% pure rate of time preference and without equity weights, is 20 €/tCO_2eq." Other works define an alternative starting value of 15 €/tCO_2eq with lifetime increases [50,51]. There are two complicating matters related to the concentration and remains of CO_2 in the atmosphere [49].

SCC is the cost of one additional unit of carbon as an estimate of the economic damages associated with a small increase in carbon dioxide (CO_2) emissions, conventionally one metric ton, in a given year. This value also represents the value of damages avoided for a small emission reduction (i.e., the benefit of a CO_2 reduction). To obtain more generalised results, three cases of GHG presented in Table 6 are analysed ($G\Delta LF^{trd}$, $G\Delta LF^{avg}$, and $G\Delta LF^{cpt}$): 13 €/twaste, 10 €/twaste and 7.2 €/twaste.

4.4.2. *ENPV*

For the economic evaluation of the incinerator national plan, ENPVs are estimated for all facility sizes, from 50 to 750 kt and under the three GHG hypotheses. Table 8 lists the ENPV estimations. The economic indicator is always higher than the financial indicator for two reasons:

- the conversion factors have a direct impact especially on the investment components, determining a reduction of their weight, and
- the positive value of SCC.

4.5. *Input of social analysis*

In addition to the avoided CO_2 emissions and air pollution, a relevant role is played by the temporary and long-term effects of sustained investment on production and employment [52].

Table 9
Job creation for all incineration sizes.

Size	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750
Skilled	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Unskilled	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Total	**12**	**24**	**36**	**48**	**60**	**72**	**84**	**96**	**108**	**120**	**132**	**144**	**156**	**168**	**180**

The social dimension of the Green Economy, with a particular focus on employment and potential effects on consumers, is an opportunity to create new employment. According to the European Renewable Energy Council, by the end of 2009, the renewable energy industry employed over 550,000 people in the European Union, and the renewable energy sector will employ a total of more than 2.7 million people in 2020 and approximately 4.4 million in 2030 [53]. In the waste management sector, both skilled and unskilled workers are involved. Table 9 exhibits, for all sizing facilities, the jobs opportunity deriving from incinerator investments [44,54].

The use of WTE presents environmental risks, such as toxic air pollution and toxic ash. These plants require effective and efficient controls to avoid the emission into the air, land and water of harmful pollutants. Thus, it would be appropriate to introduce economic sanctions, quantifiable through the SCC value. The risks associated with the use of landfills, as highlighted in Section 2, are more relevant than those of WTE. For example, the landfill use can result in groundwater pollution from leachates or toxic gases released as methane.

A correct waste management depends on waste segregation (separation) at the source. A condition to achieve this goal is education and training. Notwithstanding the relevance of the matter, this study does not evaluate the epidemiological issue of health effects in relation to WTE facilities. The frequently conflicting evidence on the association between waste incinerators and health effects is related to traditional incinerators and not to modern WTE processes [55–57].

5. Sensitivity results

Starting from the input data presented in the previous section, it is now possible to perform the sensitivity analyses on SWM considering the following:

- the three scenarios on GHG emissions ($G\Delta LF^{trd}$, $G\Delta LF^{avg}$ and $G\Delta LF^{cpt}$) and
- the four waste to energy uses ($WtoE^{75\%}$, $WtoE^{\delta(75\%)}$, $WtoE^{50\%}$ and $WtoE^{25\%}$).

The NWMP definition has required a wide number of analyses as defined before. More specifically, the results of NWMP with different WTE dimensions are presented in terms of location, size and number of facilities (Table 10).

In Fig. 1, the FNPV, ENPV and WV associated with the proposed plan are summarised.

5.1. Environmental sensitivity analysis results

Conversion of waste to energy represents a safe and environmentally friendly process as it avoids the emission of pollutants that are inside wastes, and the incineration of municipal waste is associated with the production/release of emissions lower than that from fossil fuel combustion.

Table 11 presents the environmental analysis results: reducing the use of the landfill sites is a strong necessity. The data are

Table 10
NWMP results for WTE location, dimension (kt) and number of facilities.

	$WtoE^{75\%}$		$WtoE^{\delta(75\%)}$		$WtoE^{50\%}$		$WtoE^{25\%}$	
Piemonte	700	1	500	1	500	1	0	0
Valle d'Aosta	0	0	0	0	0	0	0	0
Lombardia	400	1	400	1	0	0	0	0
TrentinoA.A.	0	0	0	0	0	0	0	0
Veneto	500	1	500	1	350	1	0	0
Friuli V.G.	0	0	0	0	0	0	0	0
Liguria	600	1	500	1	400	1	0	0
Emilia Romagna	750	1	500	1	550	1	0	0
Toscana	750	1	500	1	600	1	0	0
Umbria	0	0	0	0	0	0	0	0
Marche	400	1	400	1	0	0	0	0
Lazio	750–500	2–1	500	4	750–550	1–1	650	1
Abruzzo	400	1	400	1	0	0	0	0
Molise	0	0	0	0	0	0	0	0
Campania	750	1	500	1	500	1	0	0
Puglia	700–650	1–1	500–350	2–1	750	1	450	1
Basilicata	0	0	0	0	0	0	0	0
Calabria	350	1	350	1	0	0	0	0
Sicilia	750–400	2–1	500–400	3–1	750–500	1–1	650	1
Sardegna	350	1	350	1	0	0	0	0
Total	11,200	19	10,550	22	6200	11	1750	3

related to the national situation, but because of the huge differences between regions, the activation actions are very dissimilar at the local level.

Under the scenario, the $WtoE^{75\%}$ wastes disposed in landfill amount to 11,200 kt. The emissions reduction is estimated, and there are three hypotheses based on the absence or presence of gas capture: the range of results is from 4 to 7.2 $MtCO_2eq$. The results are linked to several factors such as the used technology in the different geographical areas and the nature of the incinerated wastes, which can significantly affect the lower calorific value and related emissions.

5.2. Financial sensitivity analysis results

The NWMP has a positive financial return according to the decisional policy adopted. It has been excluded by the realisation of facilities with a negative FNPV. This result must be analysed when possible changes in the input values occur. The sensitivity analysis indicates the strong variability of FNPV. This result is also related to the number and size of plants. The optimal national plan, indeed, indicates the construction of different incinerator facilities, both numerically that in size, under the different scenarios $WtoE^{75\%}$, $WtoE^{\delta(75\%)}$, $WtoE^{50\%}$ and $WtoE^{25\%}$. For example, the $WtoE^{75\%}$ scenario is expected to create 19 new incinerators, including 7 with size of 750 kt as already shown in Table 10. The results of the sensitivity analysis shown in the second column in Table 12 highlight that FNPV is positive in 84% of the alternative scenarios (16 cases out of 19). The scenario $WtoE^{\delta(75\%)}$ has an additional criticism given by the constraint on the facility size: under some pessimistic variations, the maximum facility available (500 kt) presents a negative FNPV.

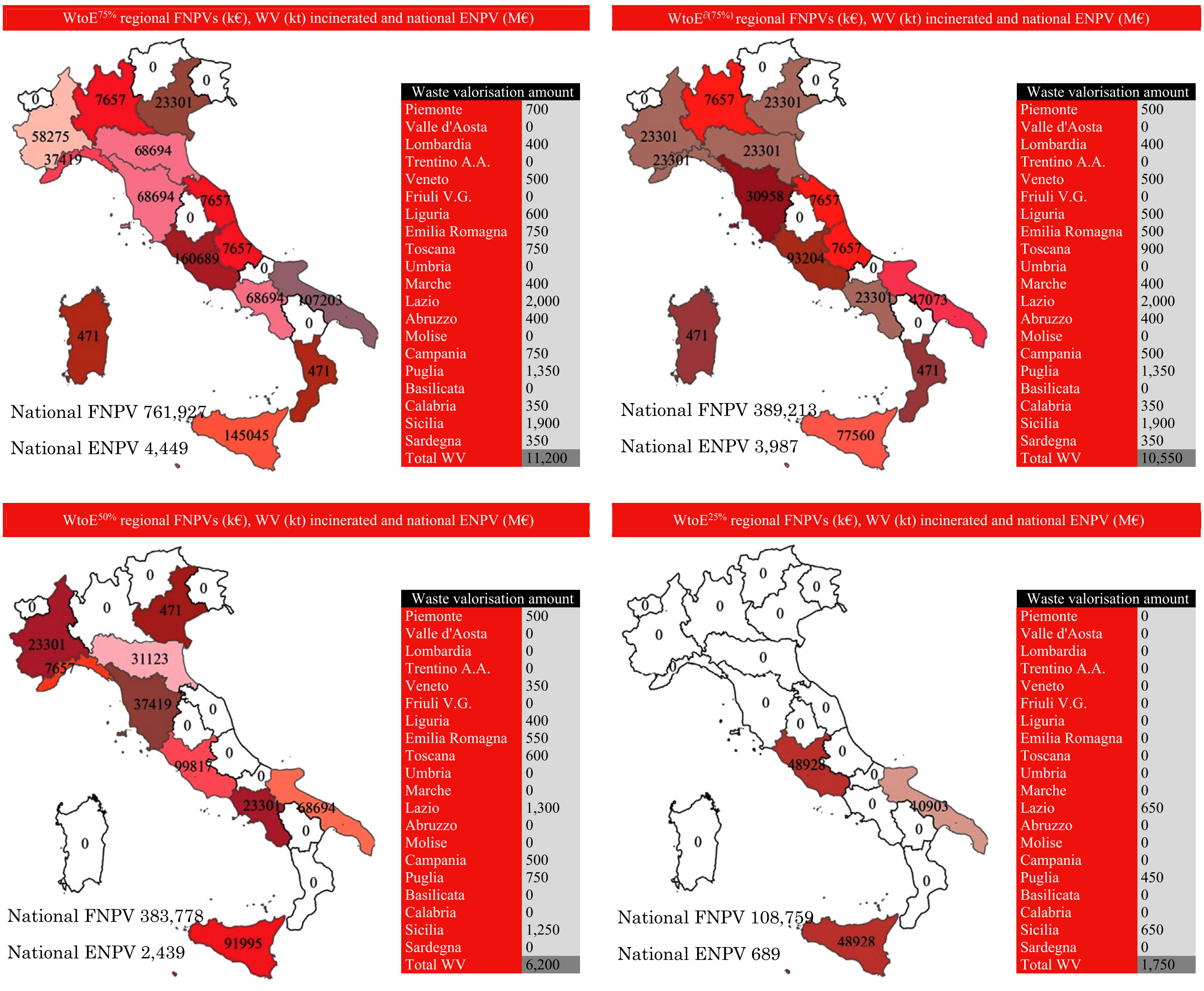

Fig. 1. Synthesis of advantages related to NWMP for energy recovery.

Table 11
GHG (ktCO_2eq) for several hypotheses of GHG reduction and incinerator use.

Indicators	WtoE$^{75\%}$	WtoE$^{\delta(75\%)}$	WtoE$^{50\%}$	WtoE$^{25\%}$
GΔLF^{trd}	7280	6858	4030	1138
GΔLF^{avg}	5600	5275	3100	875
GΔLF^{cpt}	4032	3798	2232	630

The interest rate is the most critical variable, but it is also the one least likely to be changed. The sales price of electricity and heat can easily change because of the strong dependence by Italy on energy from foreign supplies. This is certainly a convenient opportunity to further renew energy investments to reduce the energy bills for citizens and businesses as well as to obtain competitiveness in the whole energy sector. The investment cost change is instead mainly due to possible delays during lifetime, but, at the same time, it can also derive a cost reduction by the expansion of the energy recovery technology. Finally, the lower heating value is certainly subject to change. In this paper, the Italian average value of 10.4 MJ/kg is considered, but it ranges from 9.2 MJ/kg to 15.9 MJ/kg with a FNPV between 14.7 M€ and 77.4 M€ for a 500 kt plant [45].

5.3. Economic sensitivity analysis results

The economic analysis should not be interpreted as an alternative to the financial analysis. Renewable energy requires strong investments and a connected need for relevant incentive mechanisms. This has often led to characterisation of such investments by negative FNPV and positive ENPV, as determined by the economic benefits associated with the reduction of polluting emissions. Because of the Kyoto mechanisms, local governments provide incentives for the development of green energy projects and may enhance returns on investment. Consequently, green investments have positive FNPV and increased ENPV. The sensitivity analysis of the economic index values shown in Table 13 confirms the cost-effectiveness of the implementation of the national plan. The best results are associated with the situations in which incinerators are alternatives to disposal in landfills with no provision for gas capture.

5.4. Social sensitivity analysis results

The current economic context is characterised by a strong crisis that has required a staff reduction, thereby reducing the purchasing power of consumers. Thus, it is extremely relevant to create new employment opportunities, in accordance with the

Table 12
FNPV (M€) for several hypotheses of input value and incinerator use*.

	$WtoE^{75\%}$		$WtoE^{\delta(75\%)}$		$WtoE^{50\%}$		$WtoE^{25\%}$	
Interest rate								
3%	2.202	+189%	1.702	+338%	1176	+206%	332	+205%
4%	1.404	+84%	975	+151%	737	+92%	208	+91%
6%	243	*−68%*	−82	*−121%*	99	*−74%*	28	*−74%*
7%	−177	−123%	−464	*−219%*	−132	*−134%*	−37	*−134%*
Selling price of electricity								
20%	1.721	+126%	1.292	+232%	914	+138%	302	+177%
10%	1.241	+63%	841	+116%	649	+69%	221	+103%
−10%	283	*−63%*	−62	*−116%*	118	*−69%*	59	*−46%*
−20%	−197	*−126%*	−514	*−232%*	−147	*−138%*	−23	*−121%*
Heat selling price								
20%	1.318	+73%	913	+135%	692	+80%	196	+80%
10%	1.040	+36%	651	+67%	538	+40%	152	+39%
−10%	484	*−36%*	127	−67%	230	*−40%*	65	*−40%*
−20%	205	*−73%*	−135	*−135%*	76	*−80%*	22	*−80%*
Investment cost								
−20%	1.473	+93%	1.039	+167%	777	+100%	223	+105%
−10%	1.029	+35%	594	+53%	528	+36%	153	+40%
10%	143	*−81%*	−297	*−176%*	31	*−92%*	12	*−89%*
20%	−300	*−139%*	−742	*−291%*	−217	*−156%*	−58	*−153%*
Lower heating value								
12.6 MJ/kg	1.077	+41%	749	+93%	592	+52%	176	+61%
10.9 MJ/kg	909	+19%	466	+20%	458	+18%	131	+20%
9.2 MJ/kg	402	*−47%*	151	*−61%*	200	*−49%*	55	*−50%*
Positive case	84%		58%		84%		584%	
Generally there are 60 positive cases with respect to 76 analysed (79%)								

* The percentage values represent the variation of FNPV in comparison with its value in basic scenario.

Table 13
ENPV (M€) for several hypotheses of GHG reduction and incinerator use.

	$WtoE^{75\%}$	$WtoE^{\delta(75\%)}$	$WtoE^{50\%}$	$WtoE^{25\%}$
$Input^{INT}$	4449	3987	2439	689
$G\Delta LF^{trd}$	4976	4482	2731	771
$G\Delta LF^{avg}$	4581	4111	2512	710
$G\Delta LF^{cpt}$	4212	3763	2308	652

Table 14
New jobs creation for several hypotheses of incinerator use.

	$WtoE^{75\%}$	$WtoE^{\delta(75\%)}$	$WtoE^{50\%}$	$WtoE^{25\%}$
Skilled	448	422	248	70
Unskilled	2240	2110	1240	350
Total	2688	2532	1488	420

environmental limits. Green investments in renewable sector are the source of new green jobs, a strong motivation for energy recovery. The renewable energy sector requires new workers, both skilled and unskilled. In the case of strong future use of incinerators with energy recovery (with or without the hypothesis of size limitation), 2500–2700 new jobs can be created (Table 14). Notice that these estimates refer only to the workers directly employed, and do not provide the benefits that could be generated by the related industries.

5.5. *WTE remarks*

To reduce the high amount of waste diverted to landfills, urgent actions are needed in Italy. In situations where there is a failure to correctly implement the EU Waste Framework legislation, the European Commission can take actions against Member States. However, in terms of the environmental perspective (related to polluting emissions reduction), this requirement imposes the need to replace the landfills with WTE plants. Evaluating the sustainability of the NWMP also requires economic and social analyses. In fact, the financial analysis does not consider the positive externalities (economic quantification of CO_{2eq}kg not emitted into the atmosphere), so it is necessary to proceed with the economic analysis. The social analysis sets out the employment opportunities that can derive from NWMP implementation.

According to the obtained results, it is appropriate to proceed with an action plan based on energy recovery, where, more specifically, $WtoE^{75\%}$ represents the most efficient solution. Moreover, it is appropriate to note that in implementing NWMP, 34% of the waste would no longer end up in landfills and could contribute to achieving the final target of several European countries: 50% of waste recycled and 50% used for energy recovery.

6. Conclusions

The management of MSW can play a key role in tackling environmental pollution, and WTE plants represent a sustainable solution for unsorted waste management. The industries aim to reduce the volume of wastes generated by the production process. The reuse and recycling allow new products to be made out of paper, glass, plastic, metals and wood. An effective waste hierarchy focuses first on recycling and separating the collection, but it is also finalised to minimise the landfill use.

The WTE plant collects electrical and thermal energy from waste, and this leads the country to greater energy independence (like other renewable sources). Technological development has allowed modern WTE plants to become sustainable with respect to old incinerators, but strict controls are required to prevent their negative impacts on human health and the environment. Incineration with energy recovery has to be located near the point of waste generation. In this way, it is possible to reduce the environmental impact of emissions involved with transporting wastes over long distances. Waste shipment has a high environmental impact in terms of CO_2 emissions.

Correct identification of the SWM framework has been analysed in many studies. This paper proposes a NWMP for energy recovery in Italy through a quantitative analysis. The proposed analysis can be replicated in other developed countries, such as China or North

American countries, which are characterised by a higher use of landfills, and also in emerging markets. This NWMP allows reduction of pollution, creation of new jobs and the provision of financial and economic benefits.

An aspect not analysed in this work, but relevant in an optimal waste management system, is the use of tax credits. For this reason, future research will also be related to the following:

- analysis, especially where WTE implementation has been achieved, of whether tax credits are an effective way to reduce waste disposal and increase the reuse and recycling of waste material;
- complete social analysis through interviews to identify the most critical elements that determine the aversion toward implementation of WTE.

References

[1] Porter ME. Linde Cvd. toward a new conception of the environment-competitiveness relationship. J Econ Perspect 1995;9:97–118.
[2] Eckard R. Global market for incinerator technologies. SBI Energy; 2013.
[3] Eurostat. Municipal waste statistics; 2011.
[4] Mangoyana RB, Smith TF, Simpson R. A systems approach to evaluating sustainability of biofuel systems. Renew Sustain Energy Rev 2013;25:371–80.
[5] Cucchiella F, D'Adamo I. Issue on supply chain of renewable energy. Energy Convers Manag 2013;76:774–80.
[6] Manan ZA, Shiun LJ, Alwi SRW, Hashim H, Kannan KS, Mokhtar N, et al. Energy efficiency award system in Malaysia for energy sustainability. Renew Sustain Energy Rev 2010;14:2279–89.
[7] Shi VG, Koh SCL, Baldwin J, Cucchiella F. Natural resource based green supply chain management. Supply Chain Manag 2012;17:54–67.
[8] Meyar-Naimi H, Vaez-Zadeh S. Sustainable development based energy policy making frameworks, a critical review. Energy Policy 2012;43:351–61.
[9] Kurland NB, Zell D. Green management: principles and examples. Organ Dyn 2011;40:49–56.
[10] Molina-Azorín JF, Claver-Cortés E, López-Gamero MD, Tarí JJ. Green management and financial performance: a literature review. Manag Decis 2009;47:1080–100.
[11] Cucchiella F, D'Adamo I, Gastaldi M. Italian energy portfolio analysis: an interactive renewable investments tool. Adv Mater Res 2013;739:768–76.
[12] Amigun B, Musango JK, Stafford W. Biofuels and sustainability in Africa. Renew Sustain Energy Rev 2011;15:1360–72.
[13] Woods ND, Konisky DM, Bowman AO. You get what you pay for: environmental policy and public health. Publius: J Fed 2008;39:95–116.
[14] Flammer C. Corporate social responsibility and shareholder reaction: the environmental awareness of investors. Acad Manag J 2012.
[15] Ritzkowski M, Stegmann R. Landfill aeration worldwide: concepts, indications and findings. Waste Manag 2012;32:1411–9.
[16] Singh RP, Tyagi VV, Allen T, Ibrahim MH, Kothari R. An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario. Renew Sustain Energy Rev 2011;15:4797–808.
[17] Pires A, Martinho G, Chang N-B. Solid waste management in European countries: a review of systems analysis techniques. J Environ Manag 2011;92:1033–50.
[18] Qi G, Yue D, Liu J, Li R, Shi X, He L, et al. Impact assessment of intermediate soil cover on landfill stabilization by characterizing landfilled municipal solid waste. J Environ Manag 2013;128:259–65.
[19] Tian H, Gao J, Hao J, Lu L, Zhu C, Qiu P. Atmospheric pollution problems and control proposals associated with solid waste management in China: a review. J Hazard Mater 2013;252-253:142–54.
[20] Wu E, Kan B. China waste treatment sector. Asia Pacific Equity Research-JPMorgan; 2012 p. 1–32.
[21] Wu YC, Xu LF. Analysis of the barrier factors of municipal solid waste classification recycling. Adv Mater Res 2013;726–731:2618–21.
[22] Wüstenhagen R, Wolsink M, Bürer MJ. Social acceptance of renewable energy innovation: an introduction to the concept. Energy Policy 2007;35:2683–91.
[23] Mahesh A, Shoba Jasmin KS. Role of renewable energy investment in India: an alternative to CO_2 mitigation. Renew Sustain Energy Rev 2013;26:414–24.
[24] Jacobidies MG, Winter SG, Kassberger SM. Wealth, profit or sustainable advantage: which should be the dependent variable for strategy? Acad Manag Proc 2007;2007:1–6.
[25] Chrusciak M. European waste to energy plant market. Information & Communication Technologies, Frost & Sullivan; 2013.
[26] Wagner J. Incentivizing sustainable waste management. Ecol Econ 2011;70:585–94.
[27] Xydis G, Koroneos C. A linear programming approach for the optimal planning of a future energy system. Potential contribution of energy recovery from municipal solid wastes. Renew Sustain Energy Rev 2012;16:369–78.
[28] European Environment Agency. Better management of municipal waste will reduce greenhouse gas emissions. ⟨http://reports.eea.europa.eu/briefing_2008_1⟩; 2008.
[29] Tabasová A, Kropáč J, Kermes V, Nemet A, Stehlík P. Waste-to-energy technologies: Impact on environment. Energy 2012;44:146–55.
[30] Karlsson-Vinkhuyzen SI, Jollands N, Staudt L. Global governance for sustainable energy: the contribution of a global public goods approach. Ecol Econ 2012;83:11–8.
[31] Münster M, Meibom P. Optimization of use of waste in the future energy system. Energy 2011;36:1612–22.
[32] Lombardi F, Lategano E, Cordiner S, Torretta V. Waste incineration in rotary kiln: a new simulation combustion's tool to support design and technical change. Waste Manag Res 2013.
[33] ISPRA. Rapporto Rifiuti Urbani 2012. Available from: ⟨http://www.isprambiente.it/it⟩; 2012.
[34] Cucchiella F, D'Adamo I, Gastaldi M. A multi-objective optimization strategy for energy plants in Italy. Sci Total Environ 2013;443:955–64.
[35] A2A. Available from: ⟨http://www.a2a.eu/gruppo/cms/a2a/it/index.html⟩; 2012.
[36] Gentil E, Christensen TH, Aoustin E. GHG accounting and waste management. Waste Manag Res 2009;27:696–706.
[37] Lenzen M, Murray J. Conceptualising environmental responsibility. Ecol Econ 2010;70:261–70.
[38] Stehlík P. Contribution to advances in waste-to-energy technologies. J Clean Prod 2009;17:919–31.
[39] Manfredi S, Tonini D, Christensen TH, Scharff H. Landfilling of waste: accounting of greenhouse gases and global warming contributions. Waste Manag Res 2009;27:825–36.
[40] Barton J, Issaias I, Stentiford E. Carbon – making the right choice for waste management in developing countries. Waste Manag 2008;28:690–8.
[41] Friedrich E, Trois C. Quantification of greenhouse gas emissions from waste management processes for municipalities – a comparative review focusing on Africa. Waste Manag Res 2011;31:1585–96.
[42] Cucchiella F, D'Adamo I, Gastaldi M. Modeling optimal investments with portfolio analysis in electricity markets. Energy Educ Sci Technol Part A: Energy Sci Res 2012;30:673–92.
[43] Golusin M, Ostojic A, Latinovic S, Jandric M, Munitlak Ivanovic O. Review of the economic viability of investing and exploiting biogas electricity plant – case study Vizelj, Serbia. Renew Sustain Energy Rev 2012;16:1127–34.
[44] European Commission. Guide to cost benefit analysis of investment projects. In: Hubner D, editor. European Commission, 2008.
[45] Cucchiella F, D'Adamo I, Gastaldi M. Municipal waste management and energy recovery in an Italian region. Waste Manag Res 2012;30:1290–8.
[46] Iaboni V., De Stefanis P. Aspetti economici del recupero energetico da rifiuti urbani; 2007.
[47] Cucchiella F, D'Adamo I, Gastaldi M. Strategic municipal solid waste management: a quantitative model for Italian regions. Energy Convers Manag 2014 (in press).
[48] Pizzol M, Møller F, Thomsen M. External costs of atmospheric lead emissions from a waste-to-energy plant: a follow-up assessment of indirect exposure via topsoil ingestion. J Environ Manag 2013;121:170–8.
[49] Mandell S. Carbon emission values in cost benefit analyses. Transp Policy 2011;18:888–92.
[50] Cucchiella F, D'Adamo I. Feasibility study of developing photovoltaic power projects in Italy: an integrated approach. Renew Sustain Energy Rev 2012;16:1562–76.
[51] Rentizelas AA, Tolis AI, Tatsiopoulos IP. Investment planning in electricity production under CO_2 price uncertainty. Int J Prod Econ 2012;140:622–9.
[52] Johari A, Ahmed SI, Hashim H, Alkali H, Ramli M. Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. Renew Sustain Energy Rev 2012;16:2907–12.
[53] European Renewable Energy Council. Post-2013 multiannual financial framework. Available from: ⟨http://www.erec.org/⟩; 2010.
[54] Cucchiella F, D'Adamo I, Gastaldi M. Green supply chain and the energy recovery plant in Abruzzo. Procedia-Soc Behav Sci 2011;25:54–72.
[55] Giusti L. A review of waste management practices and their impact on human health. Waste Manag 2009;29:2227–39.
[56] D'Alisa G, Burgalassi D, Healy H, Walter M. Conflict in Campania: waste emergency or crisis of democracy. Ecol Econ 2010;70:239–49.
[57] Shmelev SE, Powell JR. Ecological–economic modelling for strategic regional waste management systems. Ecol Econ 2006;59:115–30.
[58] U.S. Environmental Protection Agency. Air emissions from MSW combustion facilities. Available from: ⟨http://www.epa.gov/wastes/nonhaz/municipal/wte/airem.htm⟩; 2005.
[59] IEA Bioenergy. Municipal solid waste and its role in sustainability. Available from: ⟨http://www.ieabioenergy.com/library/179_BenefitsofBioenergy.pdf⟩; 2003.